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UV-LASER-TRIGGERED SWITCHES

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Abstract

Two techniques of UV laser triggering for high-voltage spark gaps have been developed in which a KrF laser (248nm) is used to create an ionized channel through the dielectric gas in the spark gap. First, with a low-divergence KrF laser, we have studied laser induced breakdown in SF_6, demonstrated by Rapoport et al[1] and have applied this phenomenon to trigger a 0.5-MV spark gap. Second, we have studied the use of additives to the usual dielectric gas, such as Tri-propylamine, which undergo 2-step ionization in a KrF laser field, and determined that they allow nanosecond-jitter laser triggering even with the use of a relatively low optical quality beam. Data are presented for a 0.5-MV pulse-charged switch triggered with a low divergence KrF laser at 80% of its self-breakdown voltage which demonstrate a 1-σ jitter of 150 ps.

Introduction

Particle beam and other pulse-power drivers for inertial confinement fusion require accurate triggering (± 1 ns) of gas switches at voltages up to 3 million volts and currents of up to a quarter of a million amperes.[2] We are investigating UV-laser triggering as a means of meeting these stringent requirements.

A large amount of research has already been done on laser-triggering of gas switches, and an excellent review of this work is given by Guenther et al.[3] However, most of this work has accomplished triggering by focusing a visible or IR laser at one switch electrode to create a point plasma. This technique works quite well for small switches operating below 100 KV. However, for large gaps operating at higher voltages (≥0.5 MV), it is difficult to obtain less than 5-ns jitter with this technique even when the spark gap is operated within a few percent of its self-breakdown voltage.[4]

Our scheme uses a fundamentally different mechanism to trigger the spark gaps. Instead of generating a point plasma at one electrode, we utilize a volume interaction between UV laser radiation and the insulating gas in the switch to form an ionized channel between the switch electrodes. (Figure 1) Ionized channels were formed by two different techniques. One technique uses a focused KrF laser having a low divergence angle to create a laser-induced breakdown arc between the electrodes in pure SF_6 or SF_6 bearing mixtures. Another technique uses gases, which undergo 2-step photoionization in a KrF laser field (e.g. tripropylamine), added to dielectric gases such as N_2 at the 10-30 ppm level. These additives yield significant concentrations of electrons at much lower laser power levels than are required for SF_6 breakdown, and relax the requirement on the beam quality of the KrF laser.

This paper will discuss two laser switching techniques: first, laser-induced breakdown in SF_6; and second, laser induced ionization using additives such as tripropylamine.

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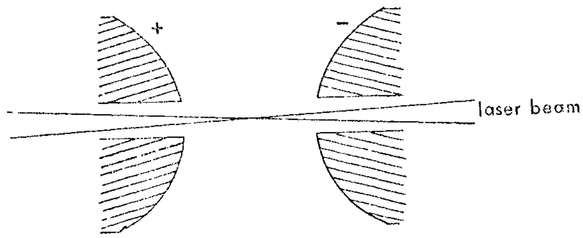

Figure 1. Schematic of laser-induced channel between electrodes.

UV Laser Induced Breakdown in SF_6

Baseline Studies

SF_6 is a popular dielectric gas for spark gaps due to its high breakdown strength for both DC and pulsed voltages. Rapoport et al[1] determined that SF_6 breaks down in KrF laser fields having power densities on the order of 4×10^9 W/cm^2 and they applied this technique to the triggering of an 80-KV, DC-charged switch. We have investigated the wavelength and pressure dependence of the UV-laser-induced breakdown in an attempt to gain an understanding of the mechanism involved. The laser beam from a Lumonics TE-262 laser (0.2J, 20 ns FWHM) was focused into a cell containing high-purity SF_6 (99.99%). Breakdown was defined as a visible arc in the SF_6 cell at the focus of the laser. The laser energy density at the focus of the lens was determined by passing the focused beam through successively smaller apertures and measuring the transmitted energy with a calorimeter. The laser pulse shape was determined with an ITT F4018 photodiode. Figure 2 shows a graph of breakdown threshold versus SF_6 pressure for the various rare-gas-halogen wavelengths accessible with this laser. The breakdown thresholds

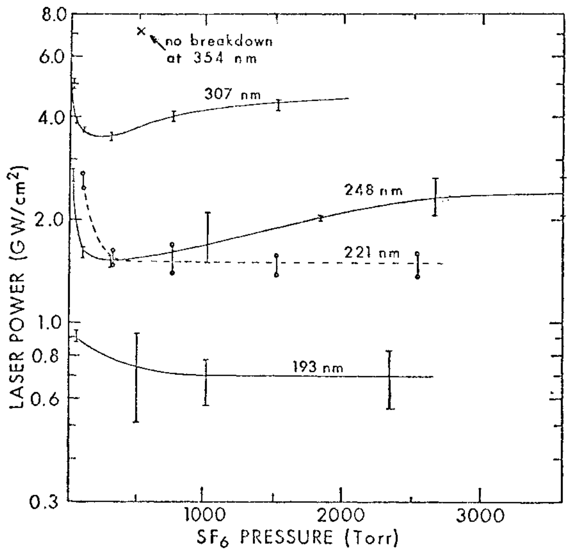

Figure 2. Breakdown threshold of pure SF_6 versus pressure and laser wavelength.

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14. ABSTRACT

Two techniques of UV laser triggering for highvoltage spark gaps have been developed in which a KrF laser (248nm) is used to create an ionized channel through the dielectric gas in the spark gap. First, with a low-divergence KrF laser, we have studied laser in1uced breakdown_in SF6, demonstrated by Rapoport et al and have appl~ed th~s phenomenon to trigger a 0.5- MV spark gap. Second, we have studied the use of additives to the usual dielectric gas, such as Tripropylamine, which undergo 2-step ionization in a KrF laser field, and determined that they allow nanosecondjitter laser triggering even with the use of a relatively low optical quality beam. Data are presented for a 0.5-MV pulse-charged switch triggered with a low divergence KrF laser at So% of its self-breakdown voltage which demonstrate a 1-o jitter of 150 ps.

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shown here for KrF (248 nm) are about a factor of two lower than the values listed by Rapoport et al.[1] This discrepancy may be due to different breakdown criteria in the two studies - we defined breakdown as a "visible arc" while Rapoport et al defined it as "a 10% reduction in the intensity of the transmitted KrF laser beam."

Switching Studies

Following some preliminary experiments, KrF laser triggering was studied on a 0.5-MV switch with a 1.77-cm electrode spacing and pure SF_6 as the insulating gas. The switch was attached to the secondary of a large air-core transformer that supplied a (1 - cos ωt) voltage waveform, rising to peak voltage in about 450 ns. The laser beam entered the switch through a 0.6-cm-diameter hole in the anode and either struck the cathode or passed through a small hole in its center. In this switch configuration, our unmodified commercial KrF laser, which had a beam divergence of a few milliradians, could produce a maximum-length breakdown arc of only 1 - 2 mm long. This short arc did not produce significantly better triggering results than in those experiments described by Guenther et al[3] with the laser focused on the cathode. To obtain longer breakdown arcs, a KrF oscillator-amplifier system was constructed. In this system, the near-diffraction-limited beam from a KrF oscillator was injected into a Lumonics TE 262 laser, which functioned as a triple pass amplifier. The optics in this system are similar to those described by Coldhar et al.[5] This laser system provided a 0.12-J laser pulse with a divergence angle of about 100 microradians, and could produce an arc in SF_6 stretching the entire length of the 1.77-cm gap. Figure 3 shows results of switching experiments using the 0.5-MV switch, pressurized with 2600 Torr of pure SF_6 and the low-divergence KrF laser. The data are plotted as delay between the rise of the laser pulse and the rise of the current pulse in the switch versus voltage on the switch. Results are shown for several different laser energies. Data taken on two different days using a laser energy of 0.12 J are shown by (x and ●). These data show an unusually flat slope of the curve of delay versus voltage. Delay changes by

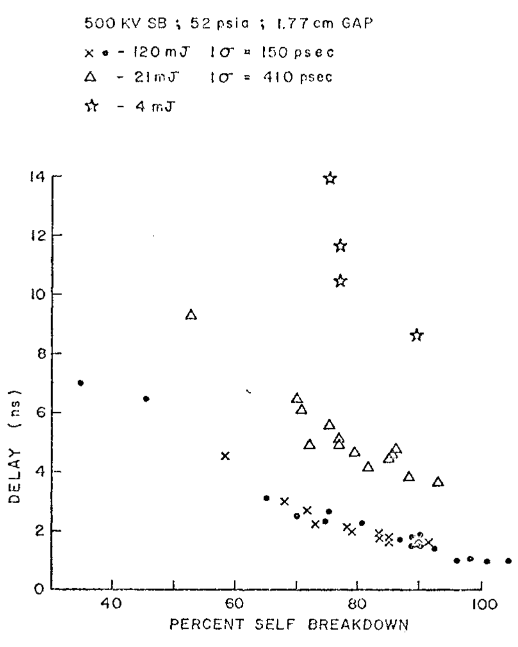

Figure 3. Delay versus voltage for KrF-laser-triggered switch pressurized with 2600 Torr of SF_6. The self-breakdown voltage for this switch was 500 KV.

less than 1 ns for a 10% variation in voltage. Also, the 1-σ jitter (defined as the standard deviation of points from the best fit line through the data) is only about 150 ps for voltages above 80% of the 0.5-MV (self-break) voltage. This jitter is about an order of magnitude lower than comparable results for an electrically-triggered switch.[3,4] It should be noted that the triggering delays of about 2 ns are comparable to streamer propagation times.[3]

2-Step Ionization of Additives

Baseline Studies

In our scheme for 2-step photoionization, a molecule is first raised to an excited state by a single photon and subsequently ionized by a second. This is accomplished with two successive photons from the same rare-gas halogen laser. A large number of molecules have been investigated. Important characteristics for an additive are an ionization threshold energy accessible by 2 photons, a bound excited state, (with minimal tendency to predissociate) a large cross-section for one-photon absorption at the laser wavelength, and 0.1 Torr or greater vapor pressure at room temperature. Molecules chosen on the above considerations were photolyzed by a rare-gas-halogen laser in one leg of a microwave interferometer. The interferometer was used to measure with nanosecond time resolution the electron densities. These measurements will be described in a forthcoming paper.[6] Some additives that met all of the above criteria and that produced large electron densities ($10^{12}/cm^3$) in the microwave transmission apparatus are listed in Table I with the appropriate laser wavelength for excitation.

TABLE I - Additives for 2-Step Ionization

Additive	Laser Wavelength
Tripropylamine	248 nm
Fluorobenzene	248 nm
NN Diethylaniline	308 nm

Switching Studies

Tripropylamine was selected as a representative additive to study switch jitter in the 0.5-MV spark gap using a 0.2 J KrF laser beam from a Lumonics TE 262 laser, in the 0.5 MV spark gap. Tripropylamine was added to 3300 Torr of N_2 (99.99% pure) dielectric gas in a 28-ppm concentration. A two-stage mixing system was used to assure uniform mixing of the gases. Triggering results for these mixed gases are shown in Figure 4. Unlike the data using SF_6 breakdown, there is a fairly steep slope to the delay versus voltage curve. The 1-σ jitter is 1.0 ns. The X and the Δ symbols represent data taken with the laser respectively striking and passing through the hole in the cathode thereby demonstrating that the switching is controlled by volumetric effects. Data taken with N_2 alone are also shown for comparison. It should be noted that these data were taken with an unmodified commercial laser. When the low-divergence laser was used, a point breakdown was observed at the focus in the N_2. Under these conditions the switching delay time was shorter and it did not depend on the presence or absence of Tripropylamine.

CONCLUSIONS

Both channel formation techniques reported in this paper show considerable promise for low-jitter triggering of high-voltage switches. Although the low-divergence KrF oscillator amplifier system focused into pure SF_6 gave the best triggering results, it requires a considerably higher laser power. For applications where the jitter requirements are less severe, though still tighter than can be met by electrical triggering techniques, additives can be used with an unmodified commercial KrF laser to achieve acceptable results.

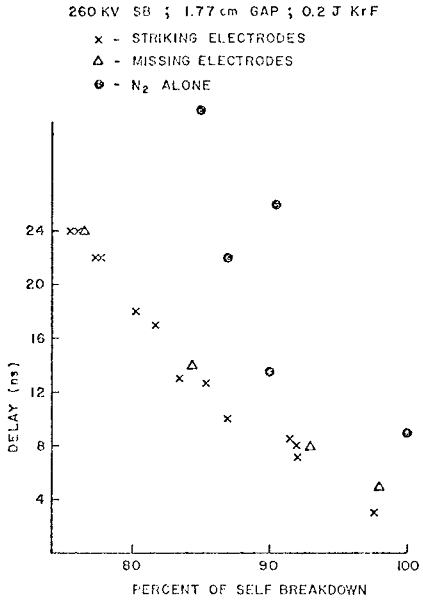

Figure 4. Delay versus voltage for KrF-laser-triggered switch pressurized with 3300 Torr of N_2 plus 28 ppm Tripropylamine; 260-KV-Self-Break Voltage.

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